Section 22 New Hampshire

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Guidance For Estimating Reservoir Yields

DECEMBER 1986

US Army Corps
of Engineers
New England Division

GUIDANCE FOR ESTIMATING RESERVOIR YIELDS IN NEW HAMPSHIRE

BY
HYDROLOGIC ENGINEERING SECTION
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NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS

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GUIDANCE FOR ESTIMATING RESERVOIR YIELDS IN NEW HAMPSHIRE

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GUIDANCE FOR ESTIMATING RESERVOIR YIELDS IN NEW HAMPSHIRE

1. PURPOSE

This report presents a review and analysis of reservoir storage-yield relationships considered generally applicable for watersheds in the State of New Hampshire. Included are sections describing the surface water hydrology of small watersheds in New Hampshire, analysis of data, development of storage-yield relations, and the application of results to some surface water supply systems in the state. The study was performed at the request of the New Hampshire Water Supply and Pollution Control Commission. The developed storage-yield relationship, shown on plate 7, should serve as a guide for performing preliminary screenings and reviews, but not as a substitute for more in-depth site specific project design studies.

2. AUTHORITY

The authority for the study and report is contained in Section 22 of the Water Resources Development Act (PL 93-251) of 1974. Section 22 reads in part as follows: ". . . The Secretary of the Army, acting through the Chief of Engineers, is authorized to cooperate with any State in the preparation of comprehensive plans for the development, utilization and conservation of the water and related resources . . ."

3. UNITS AND CONVERSIONS

The gallon is the unit of volume most used by domestic water suppliers, whereas, the cubic foot is more common to the watershed hydrologist. Some units frequently used and their conversions are listed in table 1 as an aid to common understanding.

4. DEFINITION OF TERMS

a. Dependable Yield. Dependable, safe, or firm yield is the maximum water supply that can be provided continuously from a source during a critical period. The dependable yield of a surface water source will vary with the severity of the critical drought test period selected. There is no way of reliably predicting the severest possible drought, and if there were, it probably would not be practical to design for such a condition but rather accept some degree of risk. In

TABLE I

UNITS AND CONVERSIONS

AREA

1 Acre = 43,560 sq. feet (ft.2)

1 Square Mile = 640 acres

VOLUME

1 Cubic Foot (Ft.3) = 7.48 U.S. Gallons (Gal.)

1 U.S. Gallon = 0.1337 cubic feet (Ft.3)

1 Acre-Foot (Ac-Ft.) = 43,560 cubic feet (Ft.3)

1 Acre-Foot (Ac-Ft.) = 0.3258 Million Gallons (MG)

1 Million Gallons (MG) = 3.0689 Acre-Feet (Ac-Ft.)

FLOW

1 Cubic Foot per Second (cfs) = 448.83 U.S. Gallons per minute (GPM)

1 Cubic Foot per Second (cfs) = 0.6464 Million Gallons per Day (GPD)

1 Cubic Foot per Second (cfs) = 2.0 Acre-Foot per Day (Ac-Ft/Day)

1 Gallon per Minute (GPM) = .0022 Cubic Feet per Second (cfs)

1 Million Gallons per Day (GPD) = 1.547 Cubic Feet per Second (cfs)

1 Million Gallons per Day (GPD) = 3.094 Acre Feet per Day (Ac-Ft/Day)

practice, the critical period is often taken as the period of lowest known natural historical flow in the region. This was the criteria used in this study for determining dependable yield. Another criteria sometimes used is the drought of a selected, statistically determined, frequency, i.e. a one percent annual chance event with complete utilization of storage or a 5 percent chance event with 75 percent utilization of storage, with the idea that measures could be implemented to curtail water use during the rarer events. The record drought in New Hampshire, used as the test criteria in this study, is considered to have an annual chance of occurrence in the range of 1 to 2 percent (100 to 50-year) as dis-discussed later in this report.

The current study dealt with determining dependable yield of single reservoirs operating as independent water supply sources. The combined dependable yield of integrated systems, made up of multiple reservoirs and other sources, is sometimes greater than the sum of the yields of the individual parts. For example, a river source may have a low dependable yield because of seasonally low river flow and a large reservoir may have a low yield because of inadequate catchment area for timely reservoir refill but the dependable yield of the two, as an integrated system, can be significantly greater than the sum of the two individual dependable yields. Establishing the dependable yields of comprehensive integrated water supply systems in New Hampshire was beyond the scope of this study.

b. Drought. A drought is a prolonged period of below normal precipitation which seriously affects normal streamflows and ground water levels. The long term normal annual rainfall in New Hampshire is quite ample, averaging about 40 inches; however, this is the average of many highs and lows. When rainfall is below average for a period of time the area experiences a "drought". The greatest drought experienced in New Hampshire based on nearly 130 years of record occurred during 1963-1967 when the accumulated 4-year rainfall deficiency at Concord was about 38 inches, equivalent to about one full year of normal rainfall. The accumulated 36-month (3 year) deficiency in streamflow, ending March 1967, was about 24.2 inches, as recorded at the USGS gage on the Smith River near Bristol, NH, or about 65 percent of normal for a 3-year period.

c. Reservoir Storage. Reservoir storage is the useable volume of water that can be impounded. It is that capacity that can be filled and emptied as needed for water supply purposes.

d. Watershed. Watershed is the rainfall catchment area draining to a reservoir, the surface water source.

5. NEW HAMPSHIRE SURFACE WATER HYDROLOGY

a. Climatology. The State of New Hampshire has a cool semihumid climate. Average annual temperature is about 44 degrees F., ranging from about 47 degrees F. in the lower southern coastal region to about 37 degrees F. in the north and western higher regions. An exception is the peak of Mt. Washington, of the Appalachian Mountain Range, at elevation 6,200 feet NGVD, where the mean temperature is only 27 degrees F. Mean monthly temperatures range from around 20 degrees F. in January to about 70 degrees F. in July. Mean monthly temperatures at Hanover, in west central New Hampshire at elevation 603 feet NGVD, are listed in Table II. The mean annual precipitation in New Hampshire generally ranges from about 40 to 50 inches, from the lower to the higher elevations, with the exception of the peak of the White Mountains where the mean annual precipitation is locally over 70 inches. Distribution of the precipitation is quite uniform throughout the year; however, monthly and yearly amounts are quite variable. Monthly extremes range from highs of nearly 12 inches to lows of near zero. Annual rainfall has ranged from highs of 50 inches to lows of near 24 inches. Also, much of the winter precipitation occurs as snowfall. Mean annual snowfall ranges from a low of about 60 inches in the southeastern coastal area to a high of over 100 inches in the higher mountain regions. Mean monthly and annual precipitation as recorded at Lakeport (elevation 560 feet NGVD) and Concord (elevation 350 feet NGVD) in south-central New Hampshire are listed in Tables III and IV, respectively.

b. Runoff-Streamflow. Average annual runoff in New Hampshire generally ranges from 20 to 25 inches, or about 50 percent of mean annual precipitation. Exceptions are the White Mountains where runoff in local areas will approximate more nearly 50 inches. However, these areas of high precipitation and runoff represent a relatively small percentage of the total area of New Hampshire. Rather than considering runoff a portion or percentage of precipitation, it is more the residual after evapotranspiration. Average annual evapotranspiration ranges from about 22 inches in the south to about 18 inches in the more northerly regions. Average annual runoff at 3 small unregulated short-term gaged streams in New Hampshire and one long-term station (Smith River at Bristol) are listed in Table V. Average, maximum, and minimum monthly flows for the Smith River are listed in Table VI.

TABLE II

MEAN MONTHLY TEMPERATURE

HANOVER, NH

Elevation 603 Feet NGVD

Month	Temperature (degrees F)
January	18.2
February	20.9
March	31.3
April	43.5
May	55.5
June	64.8
July	69.5
August	67.5
September	59.4
October	48.2
November	36.8
December	23.1
Annual	44.9

TABLE III

MONTHLY PRECIPITATION
AT LAKEPORT, NEW HAMPSHIRE
(119 Years of Record)

Month	Mean (inch)	Percent of Annual	Maximum (inch)	Minimum (inch)
January	3.43	8.2	8.89	.52
February	3.20	7.7	9.83	.38
March	3.67	8.8	9.29	.72
April	3.34	8.0	8.85	.86
May	3.29	7.9	7.96	.47
June	3.32	7.9	8.45	.16
July	3.77	9.0	12.56	.63
August	3.43	8.2	9.46	.31
September	3.60	8.6	10.96	.24
October	3.32	7.9	11.54	.04
November	3.84	9.2	7.90	.80
December	3.57	8.5	7.55	.72
Annual	41.80		55.88	25.39

TABLE IV

ANNUAL PRECIPITATION (INCHES)
CONCORD, NEW HAMPSHIRE
1859 - 1984
(Elev. 350 Feet NGVD)

1859- 35.15	1891- 38.36	1923- 35.15	1955- 31.16
1860- 36.13	1892- 37.82	1924- 28.65	1956- 36.75
1861- 42.70	1893- 39.40	1925- 32.91	1957- 32.01
1862- 47.61	1894- 27.64	1926- 30.15	1958- 34.69
1863- 54.31	1895- 38.10	1927- 34.28	1959- 41.19
1864- 38.74	1896- 40.09	1928- 34.47	1960- 40.92
1865- 39.15	1897- 50.05	1929- 32.83	1961- 31.99
1866- 37.12	1898- 46.02	1930- 26.10	1962- 36.82
1867- 40.21	1899- 28.57	1931- 36.52	1963- 28.53
1868- 41.27	1900- 36.16	1932- 34.11	1964- 27.90
1869- 40.59	1901- 47.16	1933- 43.56	1965- 24.17
1870- 34.45	1902- 47.19	1934- 39.97	1966- 32.60
1871- 39.92	1903- 40.80	1935- 37.08	1967- 34.19
1872- 45.56	1904- 40.53	1936- 48.79	1968- 41.32
1873- 36.58	1905- 36.08	1937- 48.05	1969- 42.30
1874- 36.99	1906- 33.28	1938- 48.42	1970- 34.67
1875- 41.61	1907- 39.36	1939- 33.28	1971- 32.80
1876- 43.50	1908- 26.25	1940- 43.21	1972- 42.07
1877- 41.66	1909- 29.94	1941- 24.95	1973- 42.04
1878- 47.79	1910- 30.19	1942- 42.05	1974- 34.45
1879- 42.06	1911- 34.13	1943- 33.61	1975- 42.28
1880- 30.48	1912- 36.43	1944- 40.67	1976- 32.51
1881- 39.60	1913- 29.04	1945- 43.94	1977- 41.64
1882- 34.05	1914- 31.17	1946- 34.79	1978- 28.87
1883- 31.35	1915- 38.15	1947- 36.08	1979- 41.27
1884- 36.21	1916- 40.13	1948- 32.86	1980- 27.06
1885- 37.71	1917- 33.00	1949- 31.09	1981- 45.84
1886- 38.89	1918- 31.86	1950- 34.53	1982- 34.74
1887- 46.85	1919- 30.76	1951- 49.27	1983- 48.09
1888- 52.33	1920- 44.53	1952- 37.45	1984- 42.24
1889- 41.00	1921- 36.22	1953- 46.30	
1890- 47.53	1922- 37.03	1954- 46.58	

TABLE V

USGS GAGING STATIONS

PERTINENT DATA

Name	Location	Drainage Area (sq. miles)	Period of Record	Average Flow (cfs)	Average Flow (inches)	Datum of Gage (ft. NGVD)
Smith River	Near Bristol, NH	85.8	May 1918-present	143	22.6	450
Stevens Brook	Near Wentworth, NH	2.94	May 1963-present	4.82	22.3	595
Stony Brook Tributary	Near Temple, NH	3.60	May 1963-present	7.14	26.9	920
West Brook Warner River	Near Bradford, NH	5.75	May 1962-present	11.5	27.1	950

TABLE VI

MONTHLY STREAM FLOW
SMITH RIVER NEAR BRISTOL, NH
DRAINAGE AREA = 85.8 Sq. Miles
1919 - 1984

Month	Mean (cfs)	Maximum (cfs)	Minimum (cfs)
January	98.9	233.00	19.20
February	99.2	578.00	20.60
March	253.0	1,242.00	29.70
April	498.0	1,077.00	183.00
May	232.0	504.00	71.50
June	103.0	353.00	20.50
July	51.5	387.00	9.00
August	33.0	168.00	4.54
September	39.5	457.00	7.62
October	64.7	267.00	8.45
November	125.0	379.00	24.90
December	134.0	393.00	22.30
Annual	144.3	223.00	64.70

c. Droughts. The greatest drought of record, in New Hampshire, occurred in 1963-1967. This was the severest in over 150 years of precipitation records in New Hampshire (1835 at Hanover) and in nearly 170 years of record in the region (1818 at Boston). The accumulated deficiency in rainfall at Concord for the period 1963-1967 was about 41 inches, which is equivalent to a year of normal rainfall. The frequencies of low rainfalls for 1, 2 and 3 consecutive calendar year durations are shown graphically on plate 2. The curves were developed using 126 years of rainfall records at Concord in a Log Pearson Type III distribution. The frequencies for multiyear durations were determined using the partial duration series method discussed in Section 6, "Hydrologic Analyses". Based on this analysis the most critical 3-year period in the 1960's drought, with an average annual 3-year rainfall of 26.9 inches, has about a 0.8 percent chance of occurrence, equivalent to a 125-year average recurrence interval. The second greatest drought of record, and the greatest prior to the sixties, occurred in 1908-1910. Its driest 3-year period was almost as severe as the 1960's 3-year drought. It had a 3-year (1908-1910) average rainfall of 28.8 inches (75 percent of normal) and a 7-year average (1908-1914) of 31 inches. The sixties drought had a 3-year average (1963-1965) of 26.9 (70 percent of normal) and a 7-year average (1961-1967) of 30.8 inches. The third greatest drought of record, and quite comparable to the first two, occurred in 1924-1927.

6. HYDROLOGIC ANALYSES

a. Hydrologic Data. Streamflow data measured and published by the U.S. Geological Survey was used exclusively in all hydrologic analyses performed as part of this study. Of a total of about 40 USGS streamflow stations currently in operation in the State of New Hampshire, the gage on the Smith River in Bristol, New Hampshire (D.A. = 85.8 square miles) was selected as a representative long term (1919 to present) unregulated stream record. Three other steamflow records, of shorter duration, were selected as typical of small unregulated watersheds and used in analyses of the 1960's drought period. The records of the later three stations started in 1962 or 1963; therefore, their records were extended back at least through 1963, using a drainage area ratio multiple with the longer term Smith River record. Pertinent data on the four gaging station records used in this study are listed in Table V.

b. Annual and Multiyear Low Flow Duration Frequencies. An annual low flow frequency analysis was made of the long-term Smith River historical flow data. Low flows were determined for durations of 1 to 183 days for each climatological year (1 April - 31 March). The annual low flows for each duration were statistically analyzed using a Log-Pearson Type III distribution, facilitated by the use of "WATSTOR" data and computer programs. Selected data was plotted for comparison using "Beards" plotting positions. The computed low flow frequency-duration curves and plotted data are shown graphically on plate 3.

Low flow frequency-duration curves were also determined for periods exceeding 1 year. Multiyear low flow analyses are critical to establishing dependable yield of water supply systems with appreciable "carry-over" storage. Analyses were made using a procedure similar to that described in Journal of Geophysical Research, Vol. 66, No. 12, December 1961, "A Partial duration Series for Low Flow Analyses," by John B. Stall and James C. Neil. The method is also similar to that described in the "Handbook of Applied Hydrology" 1964 edition by V.T. Chow, pages 18-11 to 18-15. The study was facilitated by use of the Corps of Engineers Hydrologic Engineering Center Computer Program 723-G1-L2290 entitled, "Partial Duration - Independent Low Flow Events." The procedure is basically as follows: (1) a running total of monthly flows for a selected duration is determined for the entire period of record, (2) the running total is then scanned to determine the lowest flow in the period of record, (3) once this value is determined, to avoid overlapping of data, all running total data for one duration prior and subsequent to this value is removed from further consideration and the list is again scanned for the second lowest independent event in the period of record. The process of data elimination limits the array of low flow events that can be determined. The recurrence interval or plotting positions of the low flow events are computed using "Beard's" plotting formula as presented in "Statistical Methods in Hydrology," Corps of Engineers, Sacramento District, January 1962. Computed low flow frequency curves for durations exceeding one calendar year, using the 65 years of Smith River flow data, are illustrated on plate 3.

c. Nonsequential Storage Yield Analyses. The annual and multiyear low flow frequency-duration curves are used to assess the relative severity and indicated return probability of experienced drought events, such as the drought of the sixties, as illustrated by the plotted data on plate 3. Low flow duration statistics are also used to estimate reservoir storage-yields for differing degrees of dependability. Minimum volume runoff of a selected dependability is determined from the low-flow frequency-duration curves and plotted versus duration. A 99 percent dependable analysis is shown on plates 4 and 5. The storage requirement for a selected yield and percent dependability is determined by drawing a straight line, with slope equal to the desired yield, tangent to the volume-duration curve of selected dependability. The negative vertical intercept of this line with the "y" axis represents the usable reservoir storage requirement. Using the above procedure, with the Smith River low flow-duration data, 99 percent dependable yields were determined for a range of storages and the data is plotted on plates 7 and 8. Nonsequential analyses permits a probability analysis based on the statistics of all historic flow data without regard to sequence. Such procedures, though highly useful, must be used with caution and generally verified by concurrent sequential analysis of selected historic events. One potential error in the use of nonsequential analyses for determining storage-yield relations is the fact that the analysis assumes the reservoir filled prior to the critical low flow duration being examined and that it will be capable of refilling before the occurrence of another low flow event. The reasonableness of such assumptions, for the range of storages and yields being considered, needs to be tested by sequential analysis.

d. Sequential Storage-Yield Analyses. Reservoir-yield analyses by sequential routing is simply the process of adding inflows to a balance of storage and subtracting outflows during a specified critical hydrologic period. One of the most basic graphical methods of sequential analysis is the "mass curve" or "Rippl" method. A mass curve is a plot of accumulated streamflow versus time. The slope of a line on such a graph represents flow rate and the vertical deviation between the line and the mass curve represents required storage to meet the specified flow rate. Such analyses define the critical drought period and facilitate the development of a relationship between storage and yield at a single project site. Mass curve analyses for the critical 1960's drought are graphically illustrated on plate 6. A mass curve analysis, if sufficient in length, will demonstrate the project's capability and timing of storage refill following maximum drawdown.

The mass curves for the 1960's drought, shown on plate 6, were used to develop storage-yield relations for the three small unregulated gaged streams and the long-term Smith River. It was established that the 1960's drought represented about a one percent chance event. The resulting storage-yield data for all 4 streams are comparatively plotted on plate 7. The finally adopted reservoir storage-yield curve, based on all analyses, is also shown on plates 7 and 8. The dependable yield in cfs/sq.mi. and mgd/sq.mi. can be obtained from plates 7 and 8, respectively.

e. Evaporation Adjustments. Based on the U.S. Geological Survey Hydrologic Investigations Atlas HA-7, the average annual loss by evaporation from lakes in New Hampshire varies from about 26 inches in the south to 22 inches in the north; whereas, the loss by evapotranspiration from land area varies from about 22 inches in the south to about 18 inches in the north. This results in an average net loss of 4 inches from land area replaced with lakes.

In most cases the reservoir areas represent such a small percentage of the total watershed area that any adjustments in yield due to increased lake evaporation over land area are quite negligible. However, in those instances where the reservoir area represents much of the watershed area, an adjustment may be appropriate. An average annual net loss of 4 inches per year, assuming 75 percent of it occurred during the 6-month summer season, May to October, would result in an average loss in yield during the 6-month period of 0.0007 cfs per acre of reservoir area.

7. RESULTS APPLIED TO MUNICIPAL SURFACE WATER SUPPLIES IN NEW HAMPSHIRE

As part of the study, the New Hampshire Water Supply and Pollution Control Commission requested that safe yield estimates be made for 26 municipal surface water systems in New Hampshire. The 26 communities are listed in table VII. A questionnaire was sent to all 26 communities requesting current information about their systems. Responses were received from 12 or about 50 percent. Secondly, data was taken from Engineering reports, on file at the commission, for 15 of the 26 communities. A minimum of data on the systems was also obtained from: "Public Water Supplies, Facilities and Policy Summary" by the New Hampshire Water Supply and Pollution Control Commission, dated 1983. The order of sources, of the pertinent system data listed in table VII, was generally first the questionnaire, if returned, an Engineering report if available and lastly, the 1983 Commission summary report.

Using the storage-yield relationship, developed in this study (plates 7 and 8), safe yield estimates were computed for the systems for which the minimum required information was available i.e. drainage area and reservoir storage capacity. The storage-yield relationship developed is believed most applicable to systems with significant amounts of reservoir storage per unit watershed area. The developed guidance is considered less appropriate for systems with little storage where safe yield is primarily a function of minimum streamflow. A survey of minimum flows of record of small gaged watersheds in New Hampshire revealed much spread in minimum flow per unit area, generally ranging from near zero to 0.2 cfs per square mile. The minimum flow at the long-term Smith River gage was 0.03 cfs per square mile and it was adopted for estimating safe yield for the basically "run-of-river" systems.

8. SUMMARY

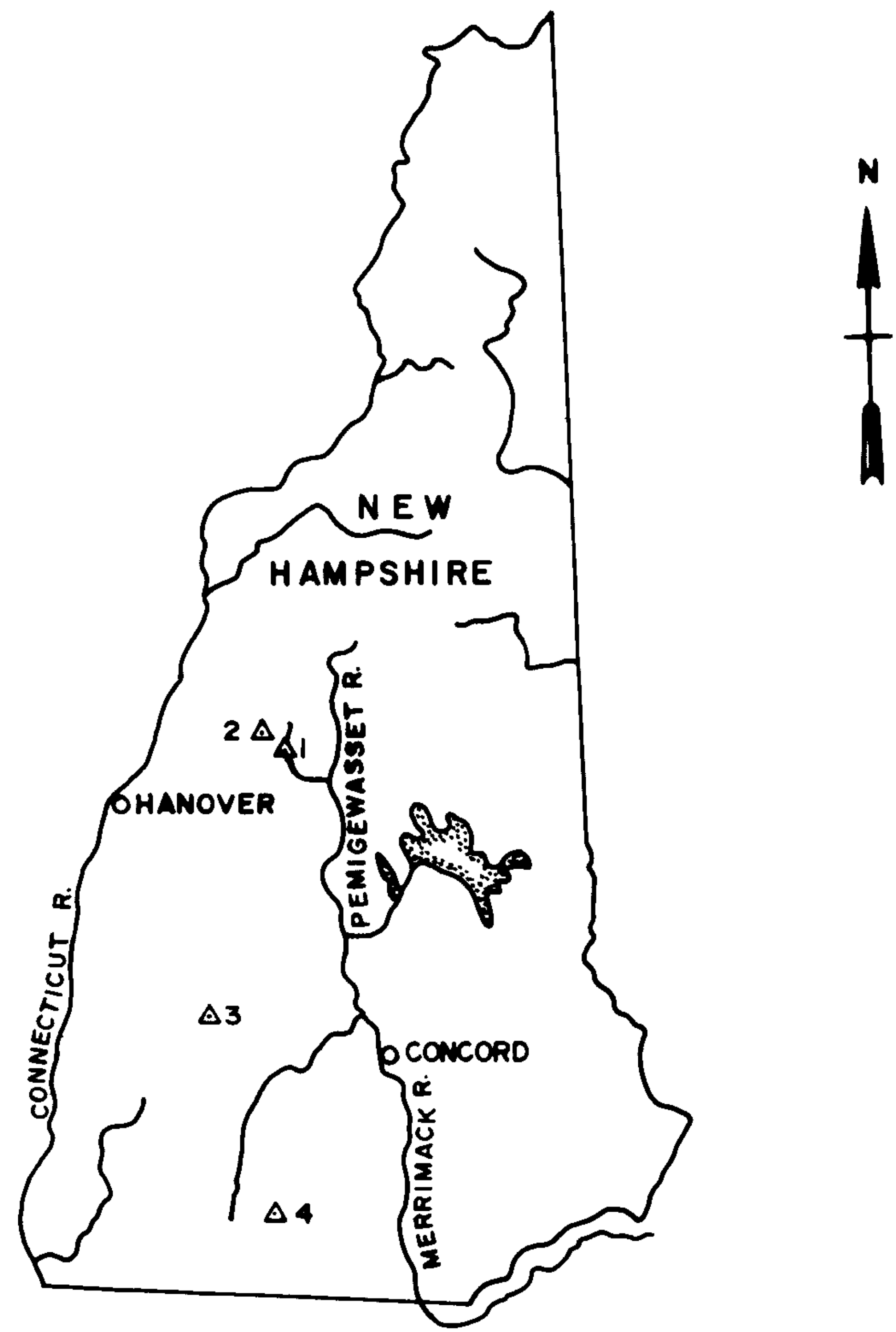
Guidance for estimating the probable safe yields of surface water systems in New Hampshire was presented using a developed Reservoir Storage-Yield relationship per unit watershed area, shown on plates 7 and 8. The storage-yield curve was based on a review of the hydrology of New Hampshire, its drought history, and a nonsequential statistical analysis of stream flow records as well as sequential analyses of the record 1960's drought at selected small gaged watersheds. The record drought compared hydrologically with the one percent chance statistical drought and was used in developing the adopted storage-yield relationship. The adopted guidance was applied in computing comparative safe yield for 26 selected municipal surface water systems in New Hampshire.

TABLE VII

PERTINENT DATA ON
MUNICIPAL SURFACE WATER SUPPLIES
IN NEW HAMPSHIRE

Community	Ref.	Reservoir	Drainage Area (sq.mi.)	Storage Capacity (ac-ft)	Surface Area (acres)	Reported Yield (mgd)	Computed Yield NEWWA Curves (mgd)	Computed Yield (mgd)
Antrim	(2)	Cambell Pond	0.5	104.4	18	0.15	0.24	0.22
Ashland	(1)	Jackson and Sky Ponds	1.3	311	39 & 13	0.55	0.68	0.60
Bethlehem	(2)	Gale & Zealand Rivers	2.25 & 7.0	2.5	-	0.8	-	-
			(total system storage not given)			(transmission cap)		
Boscawen	(1)	Walker Pond	9	(1.3×10^6 MG)	190	2.2	6.4	13
			(question total storage figure) (2-foot drawdown on 190 acres would equal 380 acre-feet and 2.7 mgd yield)					
Campton	(3)	Precinct Reservoir	2.25	2.1	1	.08	0.17	.06
Canaan	(1)	Canaan Street Lake	2.4	614	300	1.0	1.1	1.1
Carroll	(2)	Little River and Cherry Mountain	3.0 & 1.4	0.28 & 0.037			-	0.08
							(based on minimum flow estimate)	
Charlestown	(1)	Town Reservoir	5.2	40	10		0.42	0.5
Goffstown	(1)	Reservoir #1	1.1	46	6		0.24	0.2
Gorham	(2)	Ice Gulch, Perkin's Pond & Sugar Hill	1.5, 3.5 & 0	1.46, 0.78 & 3.0		0.13 & 0.32	0.4	0.3
Hancock	(1)	Juggernaut Pond	0.23	107	17.4	0.13	0.16	0.15
Haverhill (Woodsville)	(1)	Reservoir	34.2	5.5	-	-	-	0.66
							(based on minimum flow estimate)	
Hillsboro	(2)	Loon Lake	1.8	1,400	155	1.4	1.3	1.4
Jaffrey	(1)	Bullet Pond Poule Reservoir	0.4 0.7	255 20.6	48 3	0.19 0.12	0.28 0.13	0.30 0.11
Keene	(1)	Babbidge Dam	3.15	400	40	1.9	1.26	1.1
Lancaster	(2)	Garland Brook	11.7	7.7	-	0.35	-	0.26 (minimum flow)
Lincoln	(2)	Loan Pond Boyce Brook	0.5 5.3	490 0.46	18 -	0.35 0.02	0.38 0.11	0.42 0.10
Littleton	(3)	North Branch Gale Road Branch Brickyard Road	7.3 7.9	- -	- -	1.0 0.6	- -	- -
New Hampton	(2)	Mountain Pond	0.7	13.8	22	0.2	0.07	0.1
			(Storage seems low for 22 acre pond. If 3-foot drawdown, storage equals 66 acre-feet and yield equals 0.2 mgd).					
New London	(1)	Morgan Pond	1.0	518	53	0.4	0.7	0.6
Newport	(2)	Gilman Pond	1.2	334	67	0.5	0.6	0.6
Northumberland (Groveton)	(2)	Ames Brook Moore Brook Roaring Brook	1.1 1.0 0.25	3.6 Total		.06 .06 .02	0.8 0.7 0.02	.05 .05 .01
Tilton-Northfield	(2)	Knowles Pond	0.85	4.6	59.4	0.5	0.5	0.5
Troy		--	-	-	-	-	-	-
Warner	(2)	Silver Brook	2.0	16.8	4.0	0.2	0.24	0.18
Wolfeboro	(1)	Upper Beech Pond	1.1	828	136	0.85	0.77	0.80

Reference:
(1) Information from questionnaire
(2) Information from Engineering Report
(3) Information from New Hampshire Public Water Supplies 1983 Summary Report



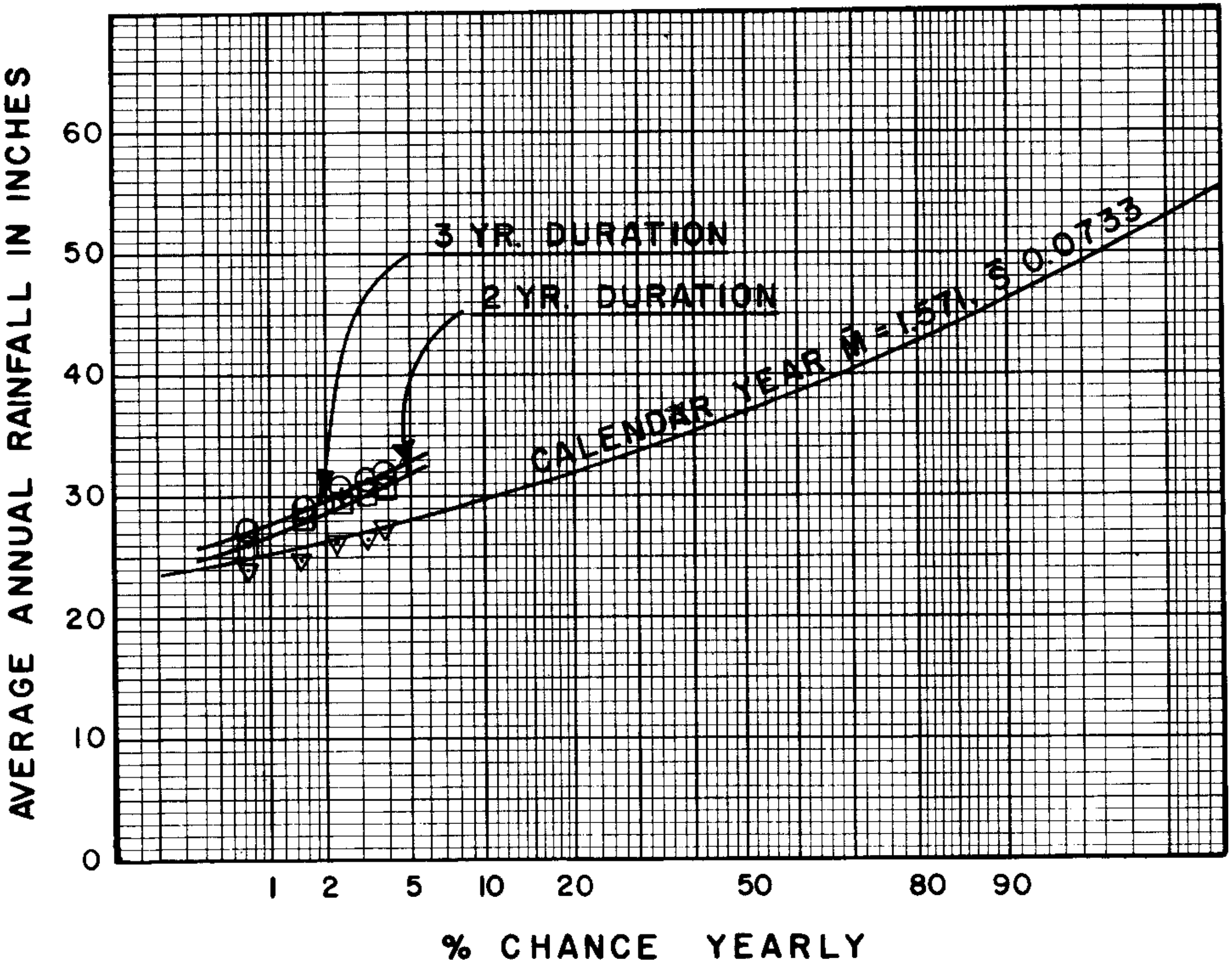
1. SMITH R.
2. STEVENS BRK.
3. WEST BR. WARNER R.
4. STONY BRK.

RESERVOIR - YIELDS

NEW HAMPSHIRE STUDY

GAGE SITES

PLATE I



⊙ 3 YR. DURATION

1963 - 65 = 26.9" /YR.
1908 - 10 = 28.8" /YR.
1924 - 27 = 30.6" /YR.

⊡ 2 YR. DURATION

1964 - 65 = 26.0" /YR.
1908 - 09 = 28.1" /YR.
1929 - 30 = 29.5" /YR.

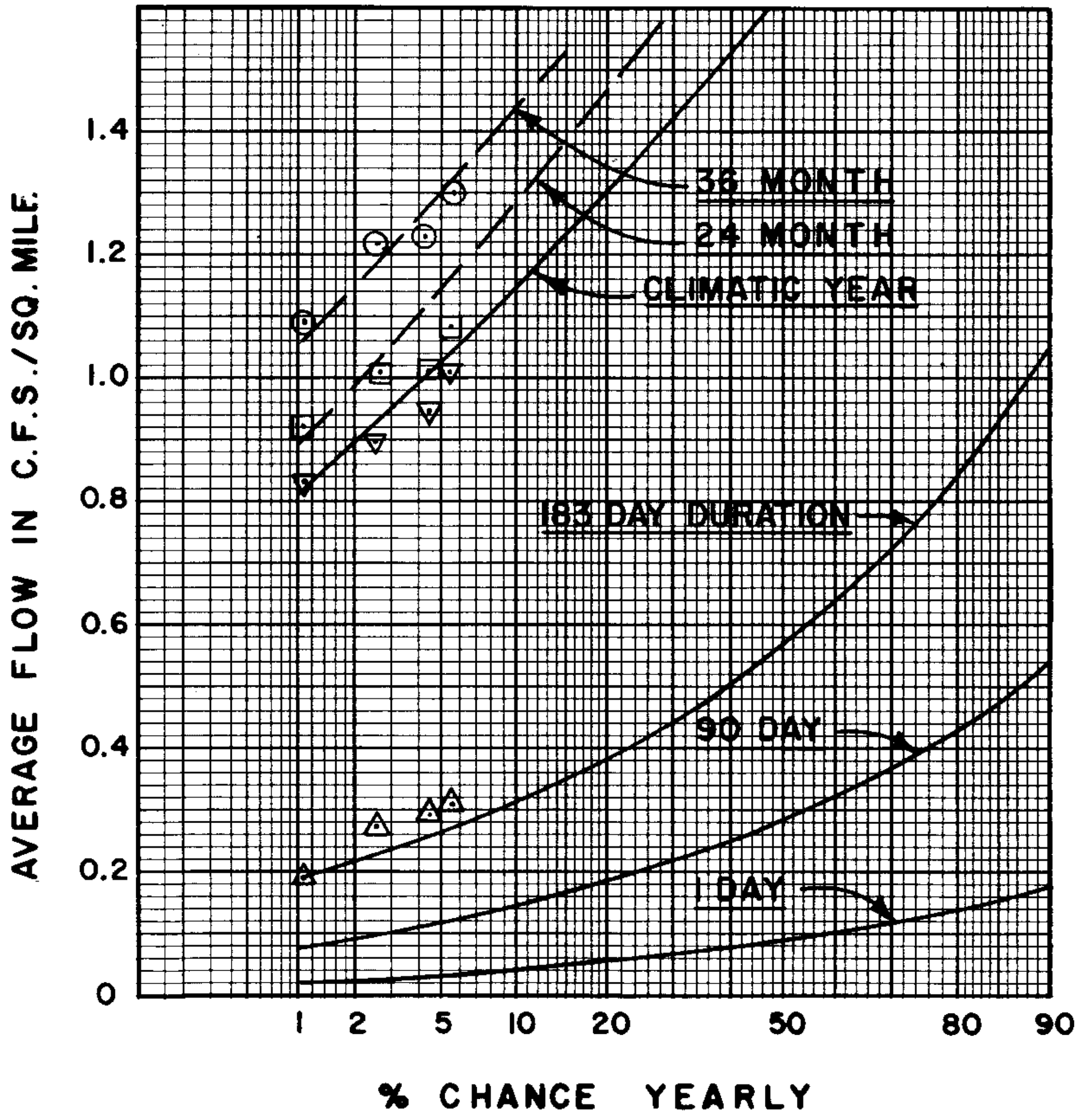
▽ 1 YR. DURATION

1965 = 24.2" /YR.
1941 = 24.9" /YR.
1930 = 26.1" /YR.

AVERAGE RAINFALL FREQUENCY
CONCORD N.H.
1859 - 1984
JUNE 1986

PLATE 2

PLATE 3



⊙ 36 MONTH DURATION

4/64 - 3/67 = 1.09 C.F.S./SQ.MI.
9/47 - 8/50 = 1.22 " "
4/30 - 3/33 = 1.23 " "
8/40 - 7/43 = 1.30 " "

⊡ 24 MONTH DURATION

5/64 - 4/66 = 0.92 C.F.S./SQ.MI.
4/30 - 3/32 = 1.12 " "
3/41 - 2/43 = 1.13 " "
4/48 - 3/50 = 1.18 " "

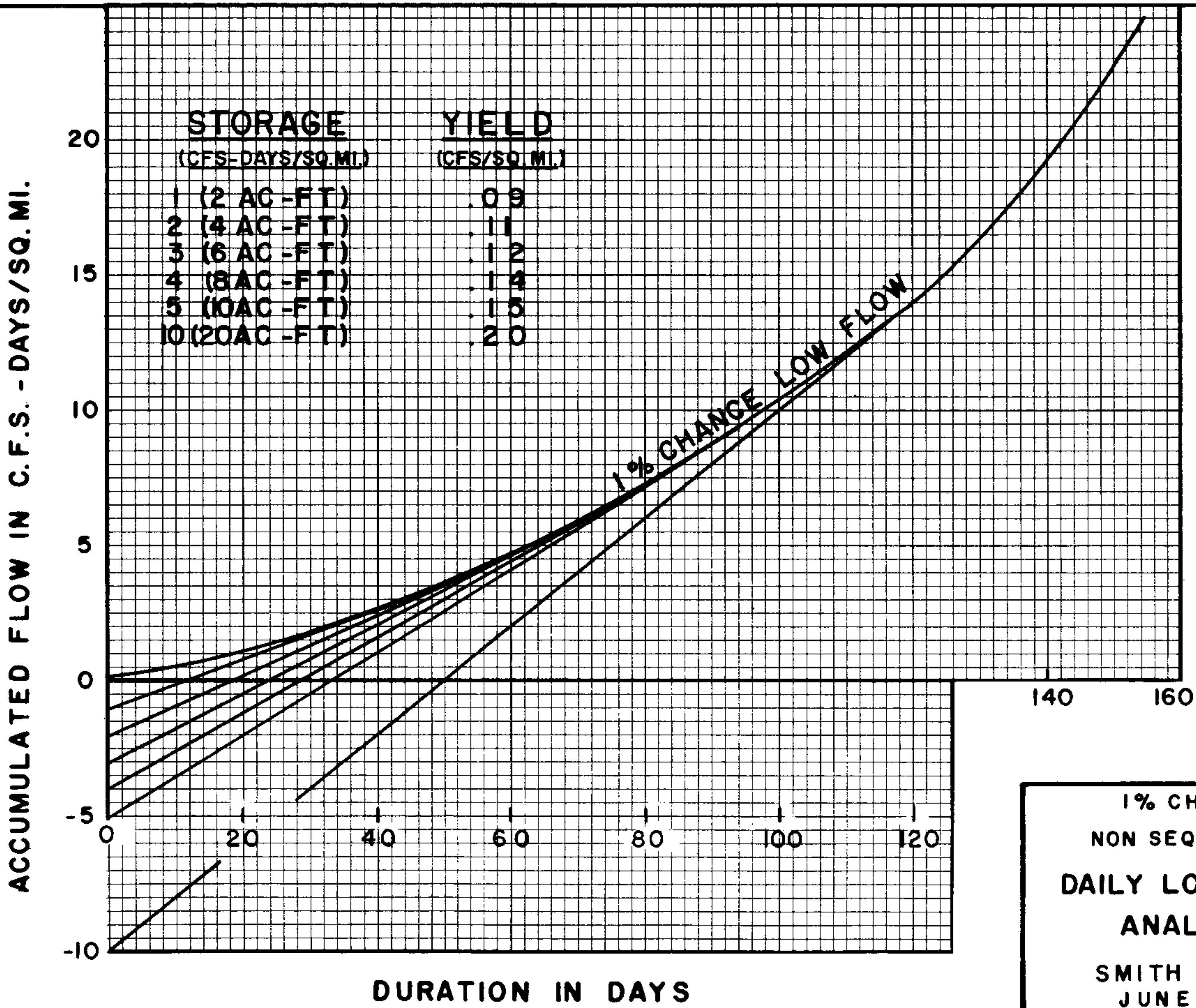
▽ 365 DAY CLIMATOLOGIC YR.
(1 APRIL - 31 MARCH)

1931 = 0.827 C.F.S./SQ.MI.
1950 = 0.897 " "
1965 = 0.944 " "
1942 = 1.013 " "

△ 183 DAY DURATION

1965 = .186 C.F.S./SQ.MI.
1972 = .279 " "
1924 = .291 " "
1979 = .303 C.F.S./SQ.MI.

LOW FLOW - DURATION
FREQUENCY
SMITH RIVER N.H.
1920 - 1984
D.A. = 85.8 SQ. MI.
JUNE 1986



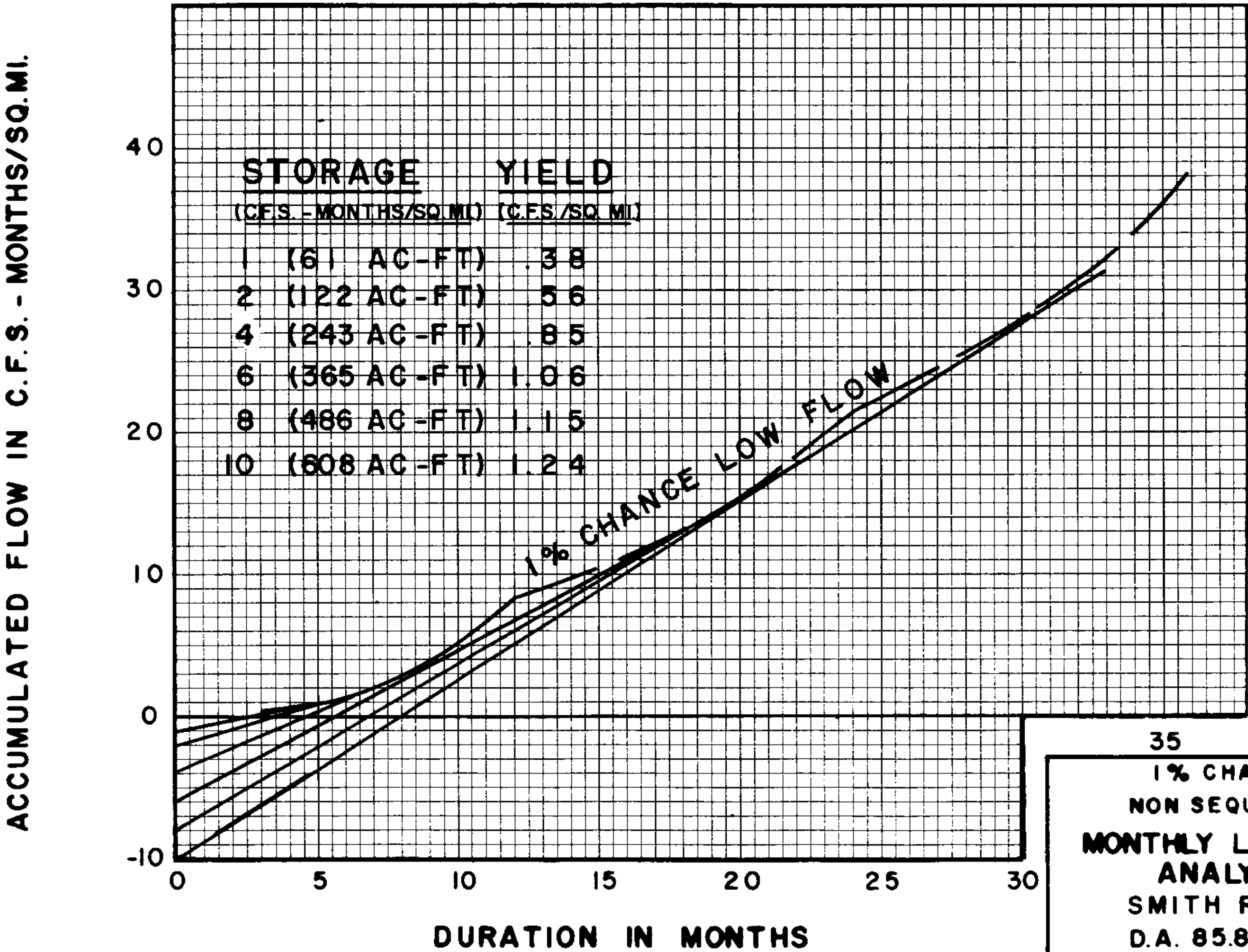
1% CHANCE

NON SEQUENTIAL

DAILY LOW FLOW ANALYSIS

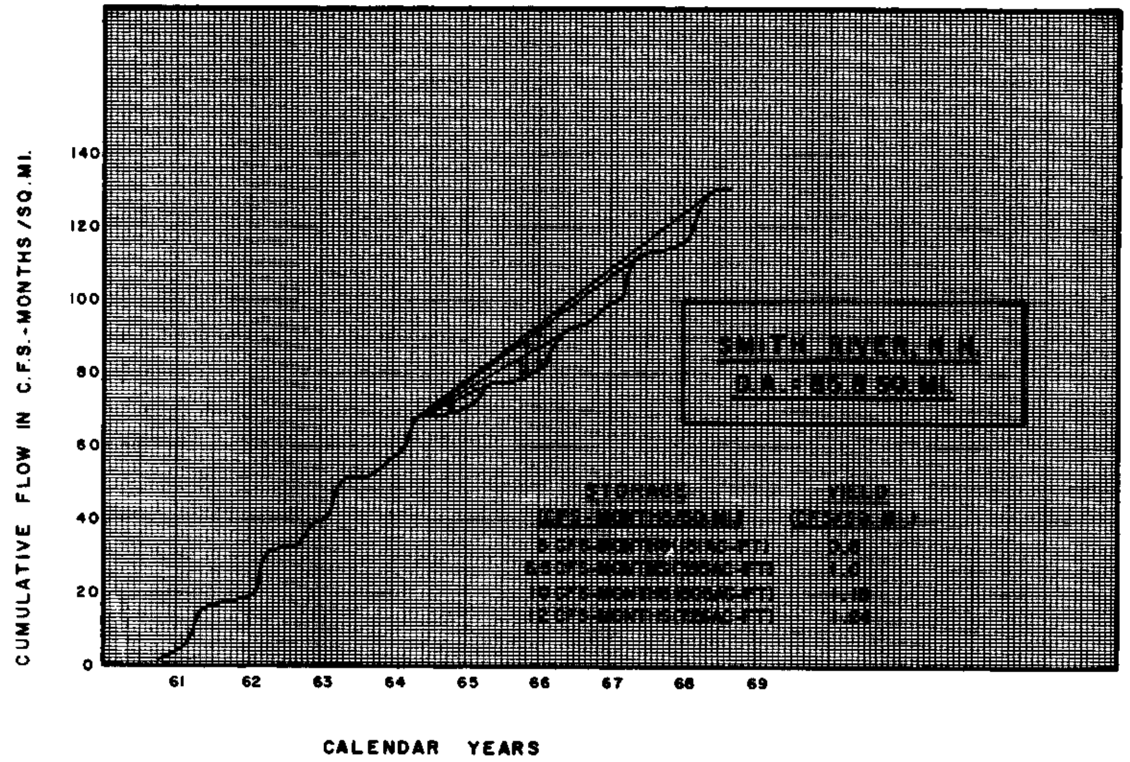
SMITH R. N. H.
JUNE 1986

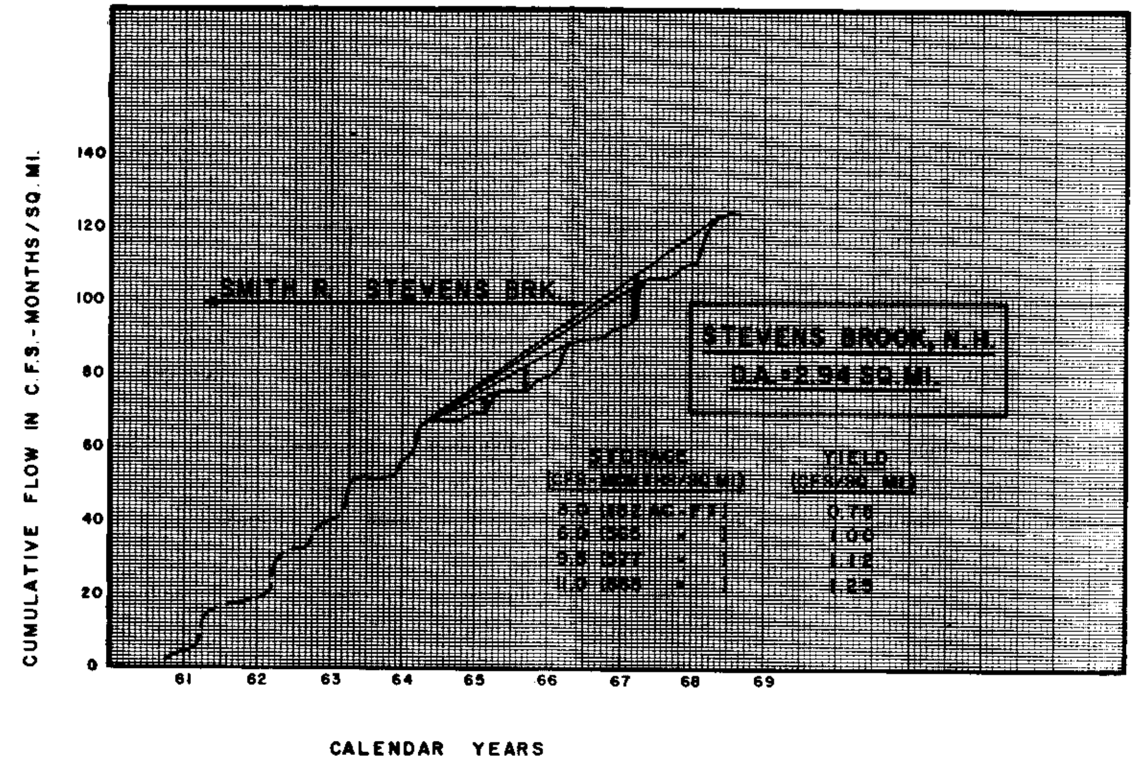
PLATE 4

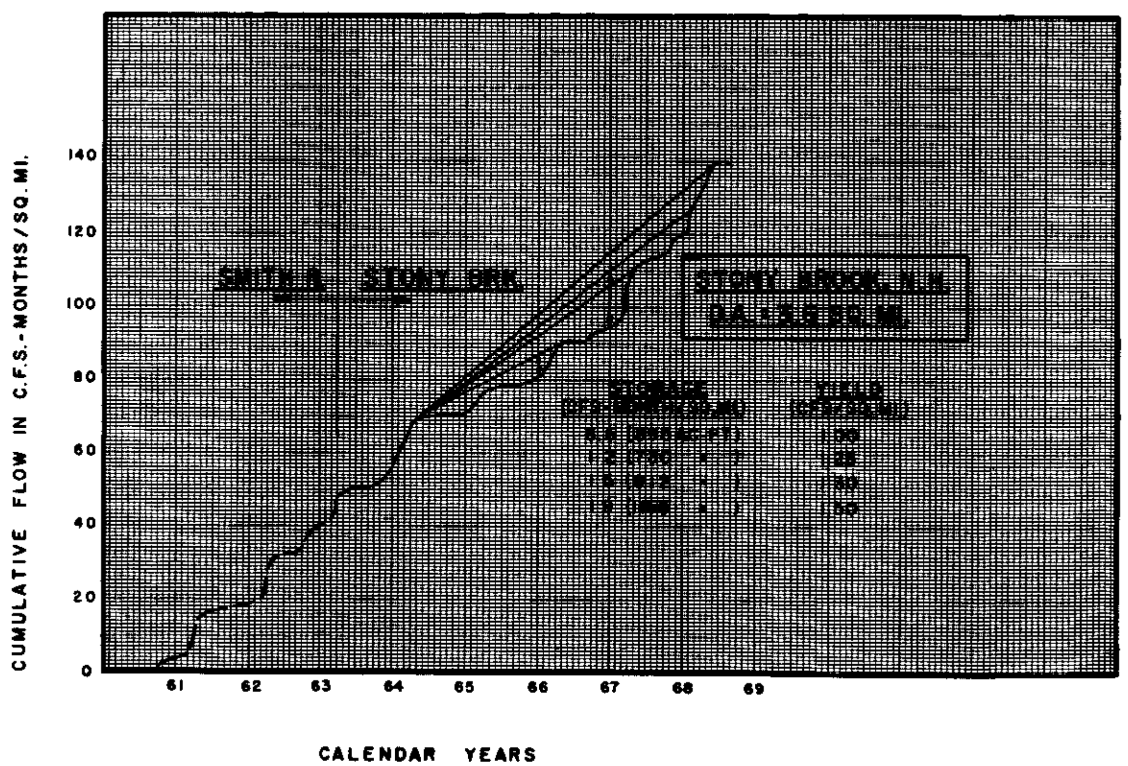


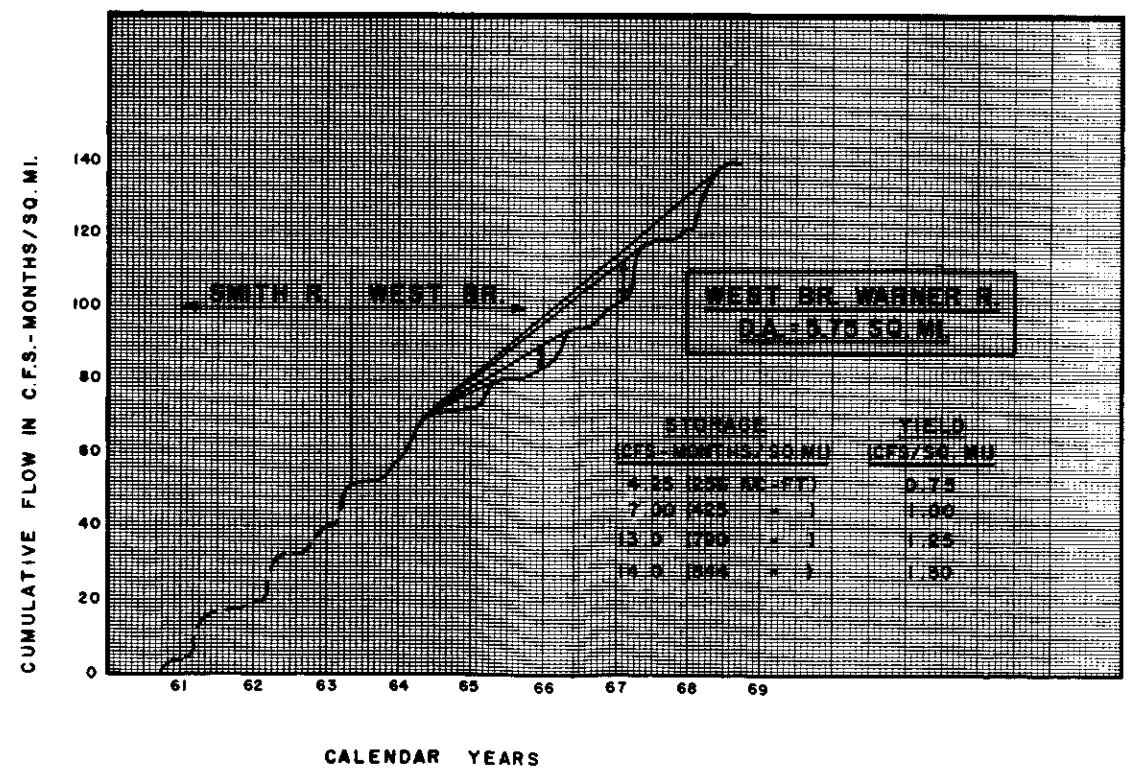
1% CHANCE
NON SEQUENTIAL
MONTHLY LOW FLOW ANALYSIS
SMITH R. N.H.
D.A. 85.8 SQ. MI.
JUNE 1986

PLATE 5









NOTE

1 CFS = 0.646 MGD

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

SEQUENTIAL

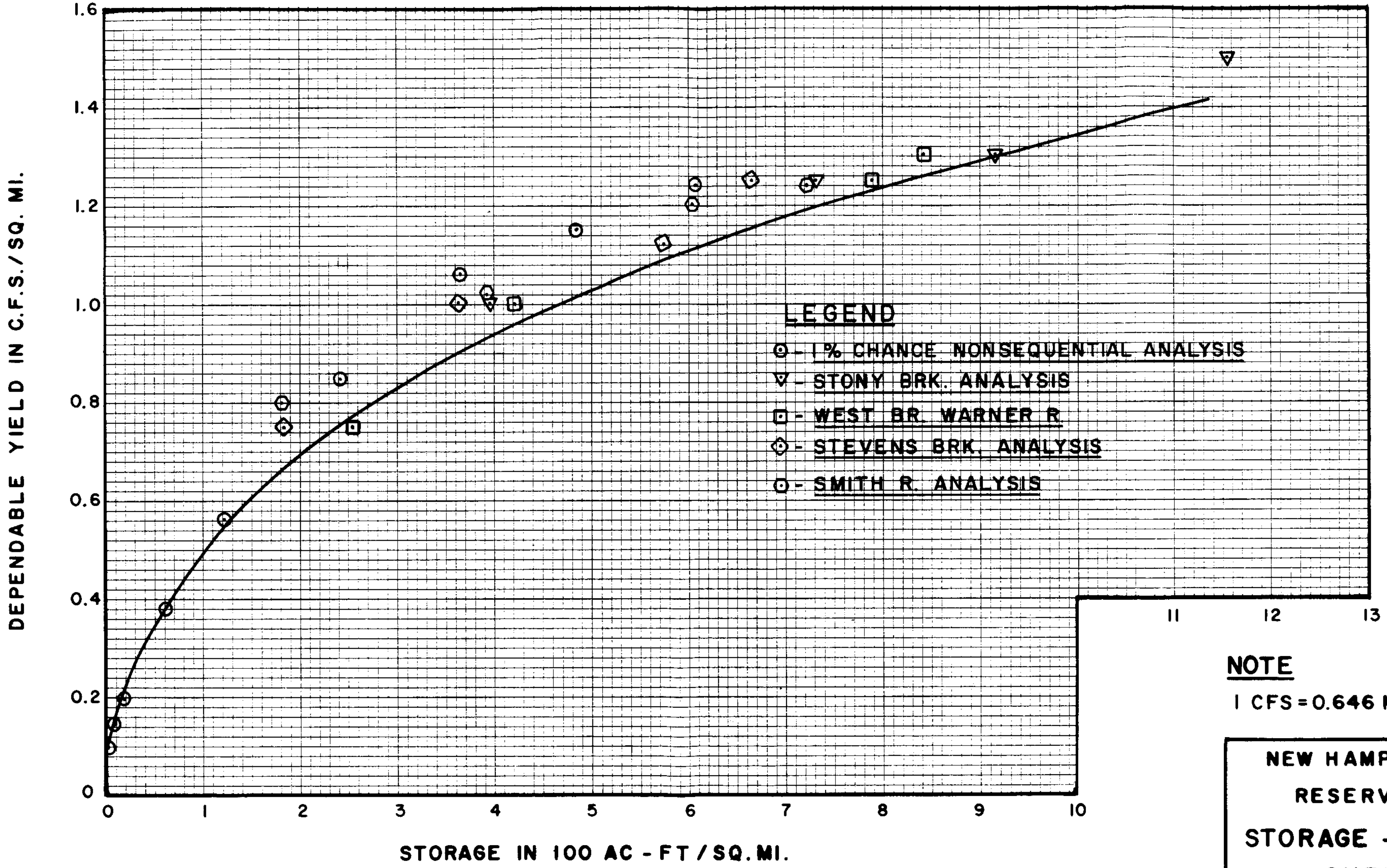
MONTHLY LOW FLOW ANALYSIS

NINETEEN SIXTIES DROUGHT

NEW HAMPSHIRE

HYDRO. ENGR. JUNE 1986

PLATE 6



NOTE

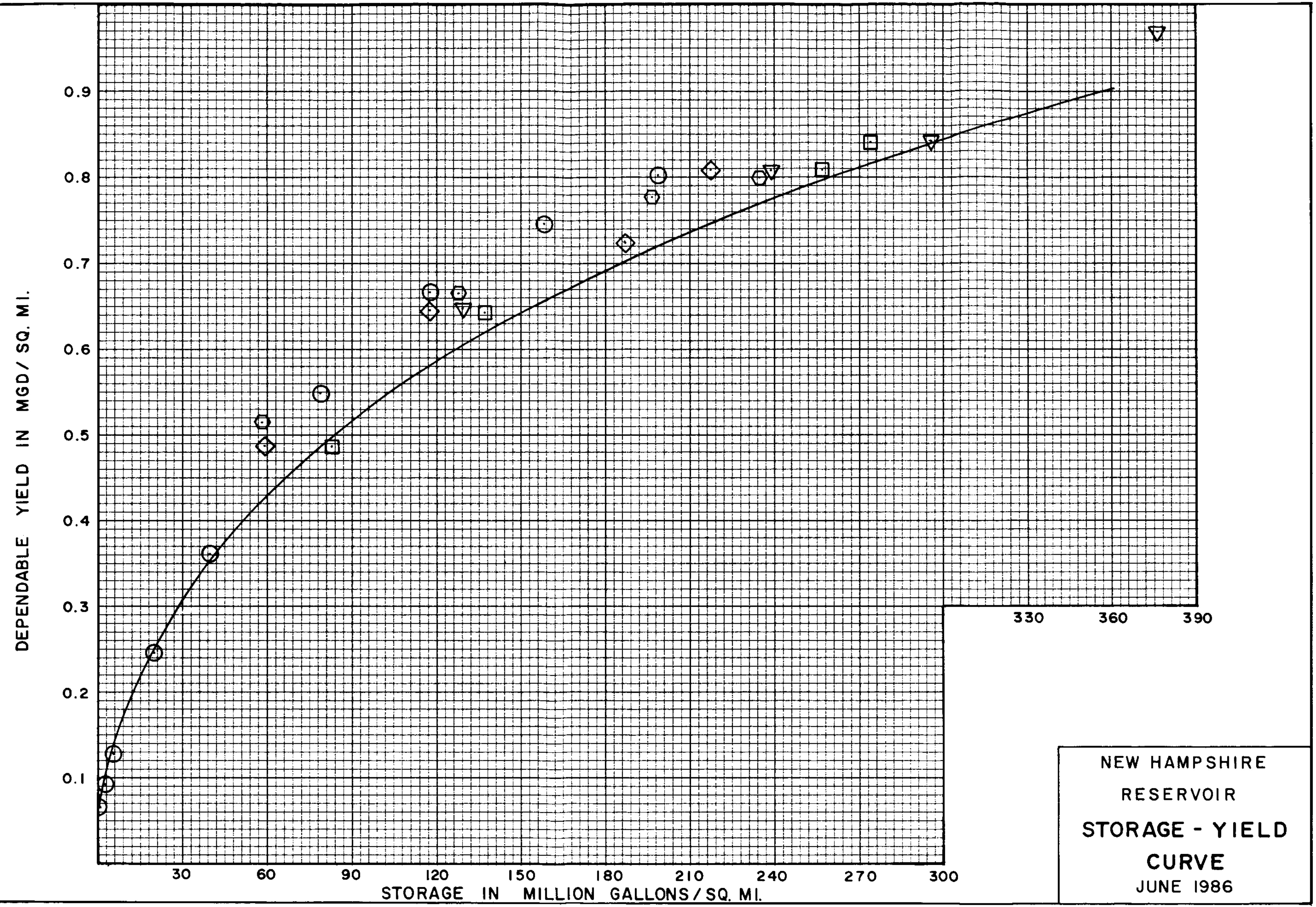
1 CFS = 0.646 MGD

NEW HAMPSHIRE RESERVOIR

STORAGE - YIELD CURVE

JUNE 1986

PLATE 7



NEW HAMPSHIRE

RESERVOIR

STORAGE - YIELD CURVE

JUNE 1986

PLATE 8